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EXPERIMENTAL INVESTIGATION ON FRICTION STIR AND SPOT WELDING OF AA 6061 AND IT'S STRENGTH MEASURMENTS

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ABSTRACT

An experimental investigation has been meted out on Hardness distribution, tensile properties and microstructure of weld, butt joints of 6061 metallic element alloy. Two completely different fastening methods are considered: Associate in nursing innovative solidstate fastening method referred to as friction stir fastening (FSW) process and Friction Stir spot fastening. The shaping pressure and mix of the plasticized material lead to the formation of a solid bond region in friction stir spot fastening (FSSW) Instead, in FSW joint, lower temperatures area unit concerned within the method because of severe plastic deformation induced by the tool motion and lower decay of mechanical properties. Within the hunk zone, a small recovery of hardness is ascertained because of recrystallization of terribly fine grain structure. Therefore, from industrial views, FSW method is incredibly competitive assist saves energy, has higher lastingness and prevents the joints from fusion connected defects.

FSW is one of the important welding processes that can be adopted for welding of Aluminum alloys with excellent mechanical properties.

KEYWORDS: Friction Stir Welding, Friction Spot Welding & Welding Joints

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Original Article

1. INTRODUCTION

It is the solid -state welding, which allows a good variety of elements and geometries to be welded and called Friction Stir Welding (FSW), W. Thomas has invented, in 1991.

Friction stir welding has a mainly used in, aerospace, shipbuilding an automobile and other manufacturing industries. The process shows a majority for welding non□heat treatable or powder metallurgy aluminum alloys, to that the fusion attachment can't be applied. Then the studies of fundamental both on the relation between microstructure with mechanical properties and process parameters and on the welding mechanism have been started recently. A great advantage is, above all the chance of connection dissimilar materials, that don't seem to be, or solely with nice difficulties weld in a position by classic fusion attachment techniques. one in each of the attainable applications is to Illustrate the attachment of highperformance materials, akin to particle bolstered metallic element alloy, to larger structures made up of a lower performance, however more cost-effective alloy. PL Thread gill (Bulletin, March 1997) made the classification of

microstructures in the first attempt. This work was based solely on information available for aluminum alloys. However, it has become evident from work on other materials that the behavior of aluminum alloys is not typical of most metallic materials, and therefore the scheme cannot be broadened to encompass all materials. A lot of comprehensive themes has been developed by TWI and has been mentioned with a variety of acceptable folks in trade and world. Recently aluminum alloy has been considered as the energy saving structural material mainly due to their lightweight. Additionally atomic number 13 is AN simply saved resource as a result of it are often recycled and therefore are often expected to be an environmental friendly bimetallic material Some of the aluminum alloy which is considered un□weld able (AA 6061) using fusion welding techniques, which produce defects and reduce the mechanical properties on the weldment and them can be successfully welded using friction stir welding processes. **Wei Yuan [5]** Efforts to reduce vehicle weight and improve safety performance have resulted in the increased application of lightweight aluminum alloys and a recent focus on the weldability of these alloys. Friction stir spot fastening (FSSW) may be a solid state fastening technique that was developed as a unique methodology for connection metallic element alloys). Throughout FSSW, the resistance heat generated at the tool-workpiece interface softens the encompassing material, and also the rotating and moving pin causes material flow. The shaping pressure and admixture of the plasticized material end in the formation of a solid bond region. The present work investigated the result of tool styles and method parameters on microstructure and mechanical properties of friction stir spot welds. Totally different tool styles were compared and method parameters were optimized for specific aluminum alloy 6016 (AA6016) supported lap-shear check. The result of a paint-bake cycle weld properties was additionally studied. Totally different failure modes for welds were projected and maintained. Material flow throughout FSSW employing a step spiral pin was studied by moldering the attachment method and examining dissimilar alloys spot welds that allowed an image of fabric flow supported their differing etching characteristics. The formation and management of a skew “Y” form chemical compound layer were investigated. The movement of higher and bottom sheet material and their combining throughout FSSW were ascertained. **D.-A. Wanga[6]** Microstructures and failure mechanisms of friction stir spot welds in aluminum 6061-T6 lap-shear specimens square measure investigated experimental observations. Optical micrographs of the cross sections of friction stir spot welds in lap-shear specimens before and when failure square measure examined. These frictions stir spot welds show the failure mode of lump pulls out beneath lap-shear loading conditions. The experimental observations recommend that beneath lap-shear loading conditions, the failure is initiated close to the attainable original notch basketball shot the stir zone (SZ) and also the failure propagates on the circumference of the lump to final fracture. Small indentation hardness knowledge of base metal (BM), heat affected zone (HAZ), thermal-mechanical affected zone (TMAZ) and SZ square measure obtained. The interface between the HAZ and also the TMAZ is that the softest region, wherever the cracks of friction stir spot welds within the lap-shear specimens beneath the loadings initiate and cause fractures of the specimens. **R. Padmanaban[7]** Stir Spot Welding (FSSW) is a recent welding technique used for spot welding of thin sheets. Response surface methodology (RSM) is used to develop a model for the tensile shear failure load of AA6061joined by FSSW. The experiments are conducted for different combinations of three parameters viz. Tool rotational speed, dwell time and shoulder diameter as per Box - Behnken design and a mathematical model is developed. The developed equation is used to find the optimum parameter combinations for obtaining joints with higher TSFL. In this study, Aluminum alloy 6061 and has been selected. Alloy 6061, a cold finished aluminum, wrought product, has the highest strength of all aluminum alloys. Due to its very high strength, both alloys used for highly stressed structural parts. Applications include aircraft fittings, gears, and shafts, missile parts, regulating valve parts, worm gears, keys, and various other commercial aircraft, aerospace and defense

equipment.

Aluminum alloy 6061 is an average to great strength, heat-treatable alloy with strength. It has very good corrosion resistance and very good weldability, although reduced strength in the weld zone. It has medium fatigue strength. The process parameters of friction stir welding are tool rotation speed (RPM), welding speed (mm/min), a downward force (kN), tool pin dimensions and shape.

Need of the Study

Aluminum alloy has been considered as the energy saving structural material mainly due to their light weight used in shipbuilding, aerospace, automobile and other manufacturing industries.

Aluminum alloys such as AA 6061 cannot be welded using fusion welding techniques, which produce defects and reduce the mechanical properties of the weld nugget.

In Friction Stir Welding process these alloys can be welded successfully and defect -free weld could be obtained without any adverse reduction in mechanical behavior. However, the effects of FSW parameters on the quality of weld have not been investigated fully.

Objective of the Study

- To prepare a strong butt weld in dissimilar aluminum alloy using Friction Stir Welding.
- To test the welded specimen for defects, microstructure, hardness, tensile and bend behavior on welded plates.
- To compare the results of microstructure with mechanical properties of the welded plates.
- To optimize the process parameters.

2. FRICTION STIR WELDING PROCESS PARAMETERS

FSW involves complicated material movement and plastic deformation. Tool geometry, Welding parameter, and joint design apply a major effect on the material flow pattern and temperature distribution, thereby influencing the micro structural evolution of material. In this section, a few major factors affecting FSW/FSP process, such as tool geometry, welding parameters, joint design are addressed. The parameters which effects are following. They are

- Spindle rotation
- Feed rate
- Depth of penetration

Mechanical Properties of Friction Stir Spot Welds

For FSW, 2 parameters square measure terribly important: tool rotation rate (v, rpm) in right-handed or counter right-handed direction and gear traverse speed (n, mm/min) on the road of joint. The rotation of tool ends up in stirring and mixture of fabric around the rotating pin and therefore the translation of thetool moves the stirred material from the front to the rear of the pin and finishes fastening method. Higher tool rotation rates generate higher temperature attributable to higher friction heating and end in additional intense stirring and mixture of fabric as are going to be mentioned later. However, it ought to be noted that resistance coupling of tool surface with workpiece goes to

manipulate the heating. So, a monotonic increase in heating with increasing tool rotation rate isn't expected because the constant of friction at an interface can amendment with increasing tool rotation rate. The quantitative relation of an influence of tool speed and weld speed is 4: three that was found by experimental results. In addition to the tool rotation rate and traverse speed, another vital method parameter is that the angle of the spindle or tool tilts in relation to the workpiece surface. An acceptable tilt of the spindle towards the trailing direction ensures that the shoulder of the tool holds the stirred

Material by rib pin and move material with efficiency from the front to the rear of the pin. Further, the insertion depth of pin into the work items (also known as target depth) is vital for manufacturing sound welds with swish tool shoulders. The insertion depth of pin is related to the pin height. Once the insertion depth is just too shallow, the shoulder of a tool doesn't contact the first work piece surface. Thus, rotating shoulder cannot move the stirred material with efficiency from the front to the rear of the pin, leading to generation of welds with an inner channel or surface groove. Once the insertion depth is just too deep, the shoulder of tool plunges into the workpiece making excessive flash. During this case, a considerable acetabular weld is created, resulting in the native cutting of the welded plates. It ought to be noted that the recent development of ‘scrolled’ tool shoulder permit FSW with 08 tool tilt. Such tools square measure, notably most well-liked for bowed joints. Preheating or cooling may be vital for a few specific FSW processes. For materials with high temperature similar to steel and metal or high physical phenomenon similar to copper, the warmth created by friction and stirring is also not comfortable to melt and plasticize the fabric around the rotating tool. Thus, it's tough to provide continuous defect-free weld. In these cases, preheating or extra external heating supply will facilitate the fabric flow and increase the method window. On the opposite hand, materials with lower temperature similar to metal and Mg, cooling are often accustomed cut back in -depth growth of recrystallized grains and dissolution of strengthening precipitates in and round the stirred zone.

3. METHODOLOGY

The trial experiments were conducted using Friction Stir Welding (FSW) on commercial AA6061. Flowchart of experimental activities is described in Figure 3.1.

Material Used in Trial Experiment

Trial experiment was conducted on AA 6061 base material, which is a pure aluminum grade contained 99.1 percentage of aluminum and tensile strength of 110 MPa. The base material composition is given in Table 3.1.

Chemical Composition

Table 3.1: Chemical Composition

MATERIAL	AMOUNT (WT. %)
AL	BAL
MG	0.8 - 1.2
SI	0.4 - 0.8
FE	MAX 0.7
CU	0.15 - 0.40
ZI	MAX 0.25
TI	MAX 0.15
MN	MAX 0.15
CR	0.04 - 0.35
OTHERS	0.05

Physical Properties

Table 3.2: Base Material Physical Properties

Property	Value
Density	2.70 g/cm³
Melting Point	650 °C
Thermal Expansion	23.4 x10-6 /K
Modulus of Elasticity	70 GPa
Thermal Conductivity	166 W/m.K
Electrical Resistivity	0.040 x10-6 Ω.m

Mechanical Properties

Table 3.3: Base Material Mechanical Properties

Property	Value
Proof Stress	270 MPa
Tensile Strength	310 MPa
Elongation A5	12 %
Shear Strength	190 MPa
Hardness Vickers	100 HV

Table 3.4: Base Material Dimensions

Length	375mm
Breadth	110mm
Thickness	5 mm and 3 mm

The base material is cut to the size as given in Table 3.4. The materials are cut according to this size for effective clamping so that the deflection of the base material is arrested and defect -free weld could be obtained without any adverse reduction in mechanical behavior.

Tool Geometry

Tool pure mathematics is that the most influential facet of the method development. It plays an important role in material flow and successively governs the traverse rate at that friction stir attachment will be conducted. The tool consists of a shoulder and pin. within the initial stage of tool plunge, the heating results primarily from the friction between pin and work piece. The tool is plunged until the shoulder touches the workpiece. The friction between shoulder and work piece ends up in the most important element of heating. Shoulder and therefore the relative size of the pin vital, consistent with the heating facet. The second performance of a tool is to and move the fabric. The tool shoulder also provides imprisonment for the heated volume of material.

Taper tool pin profiles produce defect fewer weld joints and improve the microstructure with mechanical properties on the welded plates as shown in Figure 2.1

- Tool geometry is the most influential aspect of the process development.
- It plays a critical role in material flow and in turn, governs the traverse rate at which friction stir welding can be conducted.
- The tool consists of a shoulder and pin.

- In the initial stage of tool plunge, the heating results primarily from the friction between pin and work piece.
- The tool is plunged into the workpiece till the shoulder touches.
- In between the shoulder and workpiece, the friction is generated results in the biggest component of heating.
- From the heating aspect, the relative size of the pin and shoulder is important.
- The shoulder also provides confinement for the heated volume of material.
- The second function of atool is to stir and move the material.

Tool Design

Tool pin length parameter or tool geometry are the most important item in process parameter that has the approximately 50per cent influences on weld quality and it has more influence on the quality performance of the weld. The tool geometry used in this project is shown in figure

Figure 3.1: Tool Cutters

Taper Cutting Tool

Total Length -110mm

Tool Pin -5mm

Taper Angle -10º

Shank Diameter -20mm

Friction Stir and Spot Welding Machine Specification

The MILLING MACHINE used for this project in a workshop in Balanagar Hyderabad India. Milling machine specification represented in table 1. Rotational speed 900RPM, 1100RPM, 1400RPM feed rate 31mm/min and 40mm/min used for the process. In addition, Aluminum Alloy 6061 applied in this investigation and the dimension of the joint shown in figure 3.4, 3.5. Besides Conventional (ordinary) and overlap joint FSW samples.

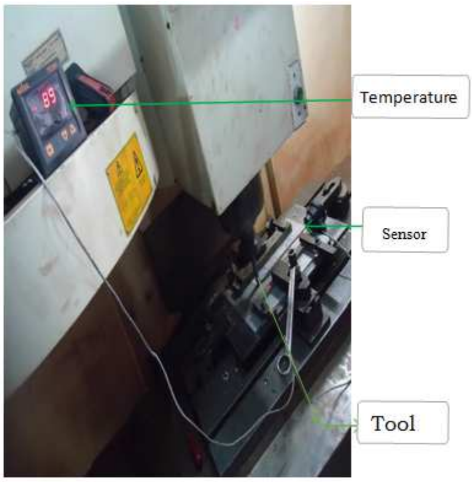

Figure 3.2: Temperature Indica

Friction Stir Welding Joints

Figure 3.3: Taper Tool (JOINT 1)

Taper Tool (JOINT 1)

Table 3.5: Taper Tool (JOINT 1)

S. No	Distance (CM)	Rpm	Feed Rate (MM)	Temperature (°C)
1	05	900	31	70
2	10	900	31	82
3	15	900	31	89
4	20	900	31	91
5	25	900	31	94
6	30	900	31	96
7	35	900	31	98

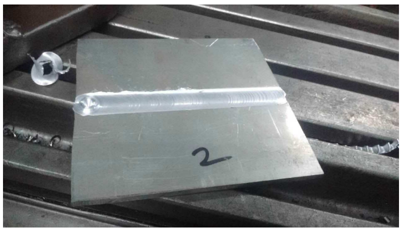

Figure 3.4: Taper Joint (Joint 2)

Table 3.6: Taper Tool (JOINT 2)

S. No	Distance (CM)	Rpm	Feed Rate (MM)	Temperature (°C)
1	05	1100	31	73
2	10	1100	31	93
3	15	1100	31	95
4	20	1100	31	96
5	25	1100	31	98
6	30	1100	31	100
7	35	1100	31	106

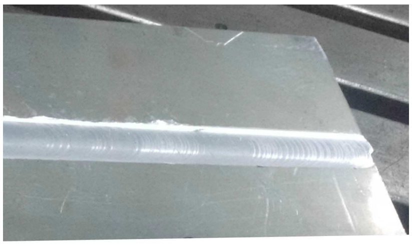

Figure 3.5: Taper Tool (Joint 3)

Taper Tool (Joint 3)

Table 3.7: Taper Tool (JOINT 3)

S. No	Distance (CM)	Rpm	Feed Rate (MM)	Temperature (°C)
1	05	1400	40	75
2	10	1400	40	96
3	15	1400	40	98
4	20	1400	40	102
5	25	1400	40	104
6	30	1400	40	107
7	35	1400	40	109

Friction Stir Spot Welding Joints

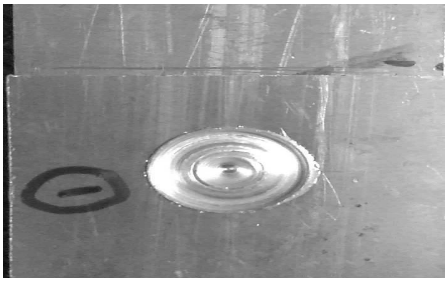

Figure 3.6: Lap Joint 1

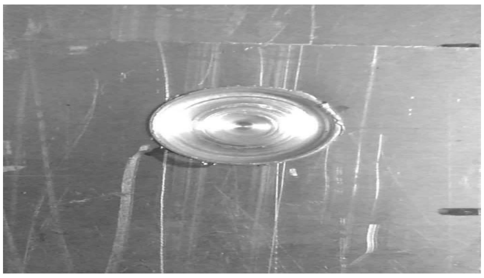

Figure 3.7: Lap Joint

4. WELD TESTING PROCEDURES

Brinell Hardness Test

It is the standard hardness testing method, Brinell Hardness Number is obtained using a perfectly spherical hardened steel10 mm diameter ball pressed against the test surface using3000 kg (=29.42 kilo Newton) static force for at least 10 sec for steel and measuring the diameters of the dent left on the surface by means of a graduated small power

microscope. The result is either calculated by looking up on prepared Tables or using a given formula (see at the end of this section).

Figure 4.1: Brinell Hardness Testing Machine

Tensile Testing

Tensile testing is also known as Tension testing, whereas testing is used for tensile strength of the material. It is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results obtained from the test are frequently used to select a material for an application, for quality control, and to predict how a material will react under other types of forces.

Figure 4.2: Universal Testing Machine

Tensile Specimen

A tensile specimen is a standardized sample cross-section. It has a gauge section in between the two shoulders. The deformation and failure can occur in gauge section, it is a small cross-section area because the shoulders are large so they can be readily gripped.

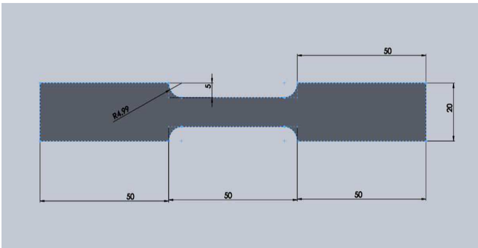

Figure 4.3: Tensile Specimen

RESULTS AND DISCUSSIONS

Experimental Results of AA6061 at 1100 r.p.m

Feed : 31mm/min

Specimen : aluminum alloy AA6061

Width : 49mm

Thickness: 5mm

Cross section area: 245mm2

Ultimate load : 24.6 KN

Tensile stress = 107.5 Mpa.

$$Tensile\ stress = \frac{ultimate\ load}{area} Mpa$$

$$BHN = \frac{F}{\frac{\pi}{2} D.(D - \sqrt{D^2 - D_i^{\,2}})}$$

Where

F = load = 250 kg.

D = ball diameter = 5 mm

D_i = impression diameter on plate = 1.8 mm.

BHN = 95

Rockwell test impression 1 = B-56

Impression 2 = B-61

Impression 3 = B-62

Ultimate load	26.4 kN
Ultimate Tensile strength	107.5
Hardness (Rockwell)	B60
Hardness(Brinell)	95

Experimental Results of AA6061 at 1400rpm

Feed : 40mm/min

Specimen: aluminum alloy AA6061

Width: 48 mm

Thickness: 5mm

Cross section area: 240 mm2

Ultimate load : 23 KN

Tensile stress = 94.8Mpa

Ultimate load	23 kN
Ultimate Tensile strength	94.8 Mpa
Hardness (Rockwell)	B55
Hardness(Brinell)	92

Experimental Results of AA 6061 at 900 rpm

Feed: 40mm/min

Specimen : aluminium alloy AA6061

Width: 48 mm

Thickness : 5mm

Cross section area: 240 mm2

Ultimate load: 23 KN

Tensile stress = 94.8Mpa.

Ultimate load	13.4 kN
Ultimate Tensile strength	55.2 Mpa
Hardness (Rockwell)	B57
Hardness(Brinell)	92

Microstructures of Friction Stir Welding

The microstructures of the FSW joints with taper tool at different speeds respectively are as shown below

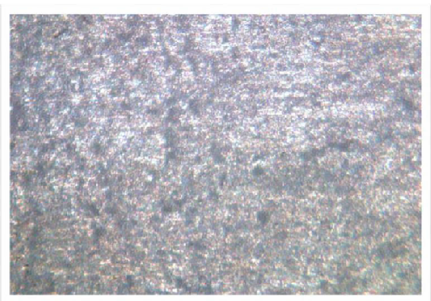

Figure 4.3: Microstructure of Taper Tool Joint1

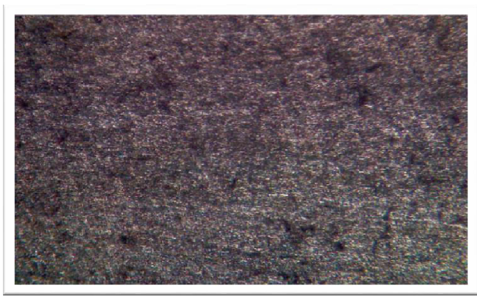

Figure 4.4: Microstructure of Taper Tool Joint2

Experimental Results of AA 6061 at 1400 rpm

Specimen : aluminum alloy AA6061

Width : 50 mm

Thickness : 3 mm

Cross section area: 250 mm2

Ultimate load : 1.8 KN

Tensile stress = 23.2 Mpa.

Ultimate load	1.8 kN
Ultimate Tensile strength	23.2 Mpa
Hardness (Rockwell)	B55
Hardness(Brinell)	91

CONCLUSIONS

Hence, from all the obtained results, it is proved that FSW is far better than friction stir spot welding.

- As the mechanical properties are good in FSW.
- Conventional pin (CP) tool and off-center feature (OC) tool were compared for friction stir spot welding of 1mm thick commercial aluminum alloy 6016-T4 sheets.
- Tool rotation speed and plunge depth, profoundly influenced thelap-shear strength of welds.
- For both tools, plunge force and spindle torque increased as tool rotation speed decreased or tool penetration depth increased.

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